Welcome to Linde Hydrogen at Shell Eco-marathon.

shellecomarathon@linde.com
Dear Shell Eco-marathon hydrogen team,

let us welcome you to the hydrogen community! Linde is the official sponsor and technology expert for hydrogen at the Shell Eco-marathon, and we are pleased to be able to support you not only on-site but also prior to the event.

We have created this small document to provide you with some useful information about hydrogen. However, you can contact us at any time by sending an email to shellecomarathon@linde.com.

The Linde Hydrogen team will be at the event ready to help you. Come and visit us in the Technical Inspection and in the Student Pit Stop Area: we are looking forward to meeting you in person.

Your Linde Hydrogen team

#LindeHydrogen
Why Linde?

The Linde Group has been developing and pioneering hydrogen (H₂) production and delivery technologies for over 25 years. We have already developed many innovative H₂ fuelling solutions for cars, buses and forklift trucks, and continue to actively drive the growing commercialisation of H₂-powered fuel cell electric vehicles (FCEV).

Our knowledge and our innovations cover everything from renewable hydrogen production, storage and distribution to dispenser manufacturing for fuelling stations and infrastructures for bus fleets, material handling vehicles and cars. Complemented by our wide range of services along the entire hydrogen value chain, our capability stretches from A to Zero.
Why hydrogen?

Hydrogen is a clean fuel – releasing only water vapour when converted in a fuel cell. It can be generated by electrolysing water, for instance. And if it is electrolysed using a regenerative source of energy, it is carbon-neutral, which means that you are not contributing to climate change if you get around on “sustainable” hydrogen. Last but not least, hydrogen is the most commonly occurring element in nature, which means that – unlike fossil fuels – it will never run out, so you don’t have to worry about depleting the earth’s natural resources.

All of this makes hydrogen the perfect energy carrier if you are interested in moving towards lower-carbon, zero-emissions mobility choices.
Hydrogen is already widely used by vehicles including cars, forklift trucks and boats, but also has uses beyond mobility, for example with Hymera™, the hydrogen fuel generator. Did you know that there is also a hydrogen car-sharing service, called BeeZero®, in Munich and that it is operated by Linde.
Let’s talk about hydrogen.

Hydrogen is an odourless, colourless and tasteless gas that is produced through natural gas steam reforming or the electrolysis of water. Lighter than air, it burns with an invisible, clean (carbon-free and soot-free) flame. It is the only fuel gas that does not contain any carbon atoms. $H_2$ has the highest thermal conductivity of all gases.

Hydrogen has been deployed as an industrial gas for over 100 years, and large volumes are used across the widest range of applications every day. Hydrogen is also set to play a defining role in the much-publicised third, “green” industrial revolution. Like electricity, hydrogen is an energy carrier – not a source of energy. It must therefore be produced. Yet hydrogen offers several key benefits that increase its potential to replace fossil fuels. Stored hydrogen, for example, can be used directly as a fuel or to generate electricity.

Hydrogen will open up regenerative, sustainable mobility choices in our everyday lives. Hydrogen-powered vehicles have a long-distance range and can be rapidly fuelled. Decades of research, development and testing have shown that hydrogen technology is a workable, economically viable alternative suited to mass deployment.
What are the benefits of hydrogen?

One of the huge benefits of hydrogen (H₂) is its versatility – it can be produced from any primary energy source which makes it limitless in terms of availability.

→ H₂ releases zero harmful emissions when it reacts with oxygen in a fuel cell.
→ It is a powerful energy carrier holding about three times more energy than petrol (based on weight).
→ H₂ can be produced from any primary energy source. It generally exists in combination with oxygen and water, as well as in organic matter such as living plants, petroleum and coal.
→ H₂ does not self-ignite or detonate in open air; like all fuels, however, it will ignite in the presence of a flame or extreme heat.
→ H₂ is odourless, non-toxic and non-corrosive.
→ H₂ can serve as a large-scale energy store for renewable electricity, hence it can help to balance fluctuating energy production such as wind power or solar.
→ Hydrogen fuel cars today enable a longer driving range (400+ km) and a faster refuelling time (3–5 minutes) compared to battery electric vehicles (BEVs).
How is hydrogen produced?

The basic distinction is made between conventional hydrogen production based on fossil feedstocks, for example through steam reforming of natural gas, and renewable hydrogen production based on renewable feedstocks such as biogenous processes (biomass gasification or biogas reforming, etc.) or electrolysis of water ($\text{H}_2\text{O}$) with wind power, water power or solar energy.

Even though hydrogen generated from fossil feedstocks has the advantage of zero-exhaust emissions, the production chain still leaves a carbon footprint. Well-to-wheel emissions of a hydrogen fuel cell car are nevertheless approximately 30 percent lower than those of a conventional diesel-powered car.

Building on conventional hydrogen production techniques and Linde’s experience of more than 100 years of hydrogen production, we are actively developing technologies to ultimately increase the share of renewably produced hydrogen.
How is windpower used to produce hydrogen?

At present, electrolysis of water using wind, water or solar power and reforming of biogas are viable alternatives that offer a zero-emissions hydrogen energy cycle.

For instance, following extensive studies and laboratory tests, we are operating a Power to Gas demo plant together with our partners at Mainz in Germany. In this facility, wind power is used to produce hydrogen via electrolysis and transported to customers such as hydrogen fuelling stations (see picture).

How is hydrogen stored?

Hydrogen can be stored as a gas, a liquid or in solid materials. It has a high gravimetric storage capacity but a low volumetric one.

Therefore to store a reasonable amount it either has to be compressed or liquefied to cryogenic temperatures, i.e. –253 °C. Hydrogen can also be stored at low pressure in the form of metal hydrides, which are used in various niche applications.

The increase in wind and solar electricity production has led to excess energy that does not match the demand of the grid. This calls for a storage solution for this excess energy until it is required. One way in which the grid can be balanced is through the electrolysis of water. The water is split into hydrogen and oxygen with the energy stored in chemical form as hydrogen. For very large volumes hydrogen can be stored in salt caverns that can hold millions of cubic metres of gas. Comparable facilities already exist in the United Kingdom and in the south of the United States.

Pressurised cylinders
Small volumes of compressed hydrogen gas are commonly stored in pressurised cylinders. They are mainly used for laboratories, welding applications and also as small refuelling solutions for the demonstration of hydrogen-powered vehicles.

Pressure vessel
A pressure vessel is the most suitable solution for storing medium amounts of hydrogen, as they are variable in volume and pressure level. This storage technology is suitable for small and medium hydrogen fuelling stations as well as industrial customers who require hydrogen for their production processes.

Liquid form
Hydrogen delivered in liquid form can be stored in volumes of up to 70,000 litres in super-insulated tanks. Even though liquefaction of hydrogen consumes more energy than central compression, the advantage is higher energy density due to reduced volume and therefore the need for less storage.
Hydrogen supply at Shell Eco-marathon.

Linde is the official sponsor and technology expert for hydrogen at the Shell Eco-marathon. At the event, the hydrogen is supplied as **compressed hydrogen cylinders**, referred to hereafter as a cylinder. The cylinders will be provided as follows:

<table>
<thead>
<tr>
<th>Type of vehicles</th>
<th>Shell Eco-marathon event</th>
<th>Cylinder dimensions working pressure at 15 °C</th>
<th>Cylinder weight / water capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prototype vehicles / urban concept vehicles</td>
<td>Asia</td>
<td>4.4&quot; x 16.7&quot; / 11.1 cm x 42.4 cm 139 bar</td>
<td>4.41 lb. / 2 litre</td>
</tr>
<tr>
<td></td>
<td>America</td>
<td>5.3&quot; x 17.1&quot; / 13.4 cm x 41.8 cm 153 bar</td>
<td>8.82 lb. / 4 litre</td>
</tr>
<tr>
<td></td>
<td>Europe</td>
<td>2.4&quot; x 10&quot; / 6 cm x 24,2 cm 200 bar</td>
<td>0.88 lb. / 0.4 litre 2.2 lb. / 1 litre</td>
</tr>
</tbody>
</table>
Hydrogen supply at Shell Eco-marathon.

The FC-powered vehicle hydrogen cylinders are provided by the organisers during the entire event. **Only one cylinder** at a time can be fitted to a vehicle. Cartridges and any other means of hydrogen storage are not permitted.

Cylinders must be installed on the vehicle under the supervision of a Fuel Marshall. Participants are not allowed to keep any cylinders in their possession overnight. Upon arrival at the circuit, team managers must contact the Fuel Marshall, who will organise all relevant logistics.

If you need any cylinder prior to the event for testing purposes, please send us a request via email indicating your team name, required quantity, specifications, delivery address and required delivery date and we will provide you with an offer.

For any inquiry, prior to the event or related to it, please contact the Linde Hydrogen team at **shellecomarathon@linde.com**.
Safety.

For the safe handling of hydrogen, it is important to know its properties and the necessary safety measures.

Hydrogen is the lightest element in the world and volatilises very rapidly in air, giving it a major advantage over petrol, which dissipates more slowly and is heavier than air.

Hydrogen is nontoxic. The primary physical hazards associated with hydrogen gas are its flammability and explosivity. This is because hydrogen can form a flammable mixture with air over a wide range of concentrations (4 to 75 percent), and very low energy is needed to ignite hydrogen-air mixtures.
Safety.

Hydrogen

→ Burns with a narrow, almost perpendicular flame that does not emit much heat.
→ A pure hydrogen flame is difficult to see in daylight.
→ Hydrogen’s flammability limit of 4 volume percent and its explosion limit of 18 volume percent are much further apart.
→ Hydrogen has an auto-ignition temperature of 585 °C.

Petrol

→ Spreads onto a surface and burns, and it produces a very broad flame that emits a large amount of heat.
→ The flame is bright.
→ Petrol’s flammability limit (0.6 volume percent) and explosion limit (1.1 volume percent) are very close together, which means that when petrol ignites, there is almost always the danger of explosion.
→ Petrol’s relatively low auto-ignition temperature (220 to 280 °C) also means that it can ignite on contact with hot metal parts such as a catalytic converter or exhaust manifold.
Safety instructions for handling H₂ cylinders at Shell Eco-marathon.

→ No smoking, no open fire close to the product – pay attention to the safety instructions.
→ Don’t throw the pressure cylinder, protect it from tilting or damage.
→ Before connecting the cylinder ensure a clean seal surface of the connection valve.
→ Ensure a clean seal surface of all connecting pipes, check connecting pipes for damage.
→ Before opening the cylinder, ensure safe cylinder storage in the vehicle.
→ Before opening the cylinder, check all the connections.
→ Before opening the cylinder, check all seals for possible damage.
→ While inserting the seals, pay attention to the correct seating (centred, connection to the sealing faces).
→ Ensure that the right type of seal is used.
→ Use protective equipment if provided (e.g. gas detector).
→ Wear antistatic clothing if possible.
→ When working with leaking or escaping H₂, provide adequate air ventilation.

For further information on how to safely handle hydrogen, please refer to the attached “Safety Advice” document or contact us.
Linde AG
Klosterhofstrasse 1, 80331 Munich, Germany

Please contact us:
shellecomarathon@linde.com